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TECHNICAL REPORT ARLCB-TR-80016

A PROPOSED STANDARD ROUND COMPACT SPECIMEN FOR PLANE STRAIN FRACTURE TOUGHNESS TESTING

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
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A round, disk-shaped specimen is proposed as a standard K_{Ic} test specimen for addition to ASTM Method E-399. The specimen is diametrically cracked, and it is loaded in the same general way as the existing standard compact specimen.
Tests and analyses are described which were performed to verify that the proposed round compact specimen and associated K solution are appropriate for a standard K_{Ic} test. The use of the round compact specimen for other fracture tests is described.

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INTRODUCTION AND OBJECTIVE

During the past few years, a number of laboratories have shown interest in a compact-type specimen with round profile for use in performing K_{Ic} and other fracture mechanics tests. Some of the interest in a round compact specimen followed from the development of the C-shaped specimen for K_{Ic} testing of material from cylinders, see ASTM Method for Plane Strain Fracture Toughness of Metallic Materials, E-399-78. But more generally, the interest in a round compact specimen is due to its shape. The round shape is easy to fabricate from a cylindrically shaped part, so when a specimen is required from an existing solid cylinder, a round compact specimen is less costly to use than a rectangular specimen. A round specimen is also easier to fabricate from rectangular bar and plate in many cases, because turning operations are generally less costly than milling. In addition, cores or blanks are often hollow-drilled from various components, including turbine rotors, steel structures such as bridges, and billets for hollow round forgings. A round compact specimen can be made easily from such blanks.

The objectives of this report are to describe the proposed round compact specimen and to describe the tests and analysis which have been performed to verify that the proposed specimen and associated K solution and test procedures are appropriate for addition to ASTM Method E-399.

SPECIMEN GEOMETRY

The dimensions of the proposed solid round specimen are shown in Figure 1 in terms of specimen depth, W. The range of a/W and B/W, the relative crack length and specimen thickness respectively, are the same as the rectangular compact specimen which is described in ASTM Method E-399. The size and vertical location of the loading holes, d/W and ℓ/W respectively, are also chosen to be the same as the rectangular compact, so that the same loading fixtures can be used for both specimens.

The portion of the diameter of the cylinder to be used for the effective specimen depth was determined by choosing D/W = 1.35. As shown in the next section of this report, the D/W ratio used in most published work on round compact specimens is 1.33. The slightly larger value was chosen for the proposed standard specimen in order that the distance between the loading holes and outer diameter (OD) of the specimen, distance X shown in Figure 2, would be increased somewhat over that of a specimen with D/W = 1.33. For the proposed specimen of Figure 1, the nominal value of X/W is 0.124; the comparable value for the rectangular compact specimen is X/W = 0.125. Based on this comparison, yielding or failure at the loading hole of the round compact specimen is not significantly more likely than with the rectangular compact specimen. Further information on the question of yielding at the loading holes of the proposed round compact specimen is obtained from measurements near the loading holes of K_{Ic} specimens. These measurements are described in a forthcoming section on K_{Ic} results.

The location of the surface on which the knife edges are located was determined by choosing c/W = 0.25, again the same as the rectangular compact specimen. For the round compact specimen, this requires that a flat surface be machined on the outer surface of the specimen. Although this involves an additional machining operation, it is considered to be worthwhile, because it provides a convenient surface for attaching or machining the knife edges used for the clip gage. In addition, it makes the location of the displacement points the same as with the rectangular compact specimen, so that the same test and analysis procedures used in testing the rectangular compact specimen can be applied to the round compact specimen.

K SOLUTIONS

Stress intensity factors have been calculated using boundary collocation by Newman [1] for the three round compact geometries mentioned in the preceding section; that is, for the full round geometries with D/W = 1.33 and 1.35 and for D/W = 1.35 geometry with a flat surface, as shown in Figure 1. Table I lists some of Newman's results and shows the effect of the ratios D/W and c/W on K_I. First, it can be seen that varying D/W from 1.33 to 1.35 has relatively little effect on the results; the largest difference between the first two columns of data in Table I is 1.3 percent for a/W = 0.2, and the difference is less than 0.2 percent for a/W $\geq$ 0.4. Further, the effect of adding the flat to the D/W = 1.35 specimen is relatively small; for a/W = 0.2 the change in K is 0.6 percent and for all other data the change is 0.1 percent or less.

Based on this result, it is clear that the K solution in the range of interest for K_{Ic} tests is unaffected by the presence or absence of the flat surface.

A wide range K expression was developed by Newman [1] based on the collocation results for the round compact specimen shown in Figure 1. It is

$$KBW^{1/2}/P = f(a/W) \tag{1}$$

where

$$f(a/W) = \frac{[2 + a/W][0.76 + 4.8\ a/W - 11.58(a/W)^2 + 11.43(a/W)^3 - 4.08(a/W)^4]}{[1 - a/W]^{3/2}}$$

which applies over the range

$$0.2 \leq a/W < 1 \quad ,$$

for a specimen with $D/W = 1.35$, $\ell/W = 0.275$, $d/W = 0.25$, $c/W = 0.25$.

Values of crack-mouth-opening-displacement (CMOD) also were calculated by Newman [1]; results for the Figure 1 geometry are shown in Table I. These values of displacement, v, correspond to half the displacement which would be measured with a clip gage attached to the knife edges shown in Figure 1. Expressions for CMOD were developed by Newman; for the Figure 1 geometry the expression is

$$\ln(BEv/P) = g(a/W)$$

where

$$g(a/W) = 1.742 - 0.495\ a/W + 14.71(a/W)^2 - 22.06(a/W)^3 + 14.44(a/W)^4$$

which applies over the range

$$0.2 \leq a/W \leq 0.8$$

for a specimen with $D/W = 1.35$, $\ell/W = 0.275$, $d/W = 0.25$, $c/W = 0.25$.

A comparison of round compact and standard rectangular compact K solutions is shown in Figure 3. The stress intensity factor solutions for the two specimens are expected to be quite similar, because the two specimen geometries are so alike, see Figure 2. However, there are some differences. For deep cracks, the material in the corners of the rectangular specimen is missing from the round specimen. This reduces the effective height, h, of the round specimen, so higher K values would be expected for the round specimen with deep cracks. This is the case as shown in Figure 3. The solid line is the wide range expression for the round compact specimen, Equation (1). The dashed line is the wide range expression in ASTM Method E-399 developed by Srawley [2] for the rectangular compact specimen. As expected, for crack length in the range $a/W = 0.5$ to 0.7, K for the round specimen is higher (by about 6 percent) than that for the rectangular specimen. For crack lengths less than $a/W = 0.5$ the difference between the K values for the two specimens decreases and for $a/W = 0.2$ the K for the round specimen is about 5 percent lower than that of the rectangular specimen. This can be explained by the larger effective height of the round specimen for shallow cracks, see again Figure 2.

The data points shown in Figure 3 are boundary collocation results for the round compact specimen from references [1] and [3]. Newman's data [1] includes the effects of the size and location of the loading holes and is the data used to obtain the wide range K expression, Equation (1), for the round compact specimen. Gross's data [3] includes only the effect of the

horizontal location of the load line by using a superposition model. As is seen in Figure 3, for cracks with a/W in the range 0.2 to 0.4, the two sets of data are different. For the case of a/W = 0.2, the inclusion of the effects of loading hole size and position relative to the crack position results in a K value which is 15 percent lower than that which results when size and position of crack and hole are not taken into account. The size and position of the loading hole relative to the crack position are sketched in Figure 3 for the case of a/W = 0.2. For this case it appears that a significant amount of "load shedding" can occur at the crack tip due to the proximity of the loading holes, so a lower K would result.

A summary of round compact K solutions based on various analyses is shown in Table II. A comparison of solutions is made using the commonly used, dimensionless function, $f = KBW^{1/2}/P$; seven solutions are compared to Newman's wide range expression, Equation (1) here. First Newman's collocation data and his wide range expression, both for the Figure 1 geometry, are compared; the expression represents the data generally within ± 0.2 percent. Work by Fisher and Buzzard [4] includes experimental compliance K data for round compact specimens; results from this work for a specimen with the Figure 1 geometry are shown in Table II. These compliance experiments give a direct representation of the actual loading hole and crack configuration; so it is significant that these results are in excellent agreement with Newman's wide range expression. Results of a recent, closed-form, asymptotic analysis by Gregory [5] also are listed in Table II. Gregory's expression, written in terms of the notation used here, is the following:

$$KBW^{1/2}/P = \left[\frac{2}{D/W(D/W-b/W)}\right]^{1/2}\left[\frac{D/W - b/W}{0.3557(b/W)^{3/2}} + \frac{2 - D/W}{0.9665(b/W)^{1/2}}\right]$$

Gregory's results for deep cracks, that is for a/W = 0.5 to 0.8, are within ± 0.3 percent of Newman's wide range expression. For shallow cracks Gregory's results, which like Gross's do not include interactions between crack and loading hole, show the same trend as Gross's results, that is higher K values than those of Newman.

The K results from four additional analyses are also shown in Table II. They are (a) some of Gross's data [3] discussed in relation to Figure 3, (b) finite element data of Mobray and Andrews [6], (c) experimental compliance data of Feddern and Macherauch [7] who proposed a round compact specimen in 1973, and (d) results from the C-shaped specimen expression [8] which is part of ASTM Method E-399. Generally all of the results are within ± 2 percent of Newman's wide range expression; the exceptions are the short crack results of Gross already discussed and some of the experimental compliance data for short cracks. Considering the inherent difficulty of the experimental compliance method and the lower sensitivity of the method for short cracks, the agreement between the compliance data and the wide range expression is very good.

COMPARATIVE K_{Ic} RESULTS

Two separate comparisons of K_{Ic} test results were obtained using round compact specimens and existing standard specimens made from the same material, see Table III for test conditions and results. Andrews [9] of General

Electric Company fabricated and tested five round compact specimens of a 1320 MPa yield strength, Ni-Cr-Mo steel which was obtained from the broken halves of specimens from the C-shaped specimen cooperative test program [10]. The mean K_{Ic} from the round compact specimens is within ± 2.9 percent of that from the C-shaped specimens. Further, the coefficient of variation of these round compact results, that is, the ratio of standard deviation to mean, is 0.041.

The second comparative K_{Ic} tests were performed by Fisher and Buzzard [4] of NASA Lewis Research Center. They fabricated and tested five round compact specimens from a Ni-Cr-Mo steel similar to that used in the C-shaped specimen tests [10], with a yield strength of 1290 MPa. Benet Weapons Laboratory supplied the material, which was from the core of a forging billet, and tested four standard rectangular compact specimens. The mean K_{Ic} from the round compact specimens is within ± 1.4 percent of that from the rectangular compact specimens. The coefficient of variation of these round compact results is 0.016.

Both groups of comparative K_{Ic} tests were performed using specimens of slightly different geometry than that proposed as the standard round compact geometry in Figure 1. Andrew's test specimens had $D/W = 1.33$ rather than 1.35, and the Fisher and Buzzard specimens had $c/W = 0.35$ rather than 0.25. But considering the collocation results in Table I, which show a maximum 0.2 percent change in K at $a/W = 0.5$ when c/W and D/W are changed by the same amounts as in the K_{Ic} tests, the K_{Ic} test results can be used to evaluate the proposed standard geometry.

As part of the round compact specimen tests described in Reference [4], displacement measurements were made using a machinists microscope in the area indicated by the dimension X in Figure 2 in order to detect any ligament yielding which might occur. The measurements indicate an average tensile strain of 0.04 percent in the direction tangent to the specimen OD and an average compressive strain of 0.07 percent in the direction perpendicular to the OD. So there was no significant yielding observed in the ligament between the loading holes and the OD. Additional description of the round compact tests performed at NASA Lewis Research Center is included in Reference [4].

OTHER FRACTURE TESTS

Other types of fracture tests are being performed using round compact specimens. The two sets of test results described in the following paragraphs are not extensive enough to validate the round compact specimen for use in other fracture tests. However, the results can be used to show the utility of the specimen for other than K_{Ic} tests and to provide guidance to those who would perform other tests.

A round compact specimen has been evaluated recently by James and Mills [11] for use in fatigue-crack growth rate testing. They performed fatigue tests in the nickel-base Alloy 718 using both a round compact specimen and the standard rectangular compact specimen. Their round compact specimen had $D/W = 1.33$, $\ell/W = 0.311$, and $a/W = 0.166$, so it was very similar in D/W ratio with somewhat smaller and more widely spaced loading holes than the

specimen proposed here. James and Mills used Newman's K expression, Equation (1) here, to calculate K over a range of a/W from about 0.4 to 0.85. Although Equation (1) was developed for a different loading hole arrangement than that used by James and Mills, for a/W above 0.4 the details of the loading no longer have much effect on K, as shown by the data of Tables I and II. The conclusion reached by James and Mills regarding the use of a round compact specimen for fatigue testing is well stated in their words. "Although a large number of specimens were not tested, the results of this study suggest that the standard compact specimen and the round compact specimen yield equivalent results for room temperature and elevated temperature fatigue-crack growth rate testing."

The round compact specimen proposed here should be directly suitable for J_{Ic} testing. One of the two specimens used in the J_{Ic} test procedure [12] is the rectangular compact specimen. Since the K solutions of the round and rectangular compact specimens differ by only about 6 percent in the $0.5 < a/W < 0.7$ range, where J_{Ic} tests are done, the round compact specimen should be nearly equivalent to the rectangular compact in J_{Ic} testing. But of course, the use of the round compact as a J_{Ic} specimen must be verified by both experimental and analytical work.

Some recent J_{Ic} tests with a 310 MPa yield strength carbon steel support the contention that the round compact specimen is equivalent to the rectangular compact specimen for J_{Ic} testing. Figure 4 shows the J versus crack growth data from four round compact specimens along with data from standard rectangular compact specimens of three sizes. The round compact specimen

dimensions are similar to those of Figure 1 and are the following: $D/W = 1.33$, $\ell/W = 0.267$, $d/W = 0.267$, $B/W = 0.533$. The solid line in Figure 4 is a linear regression representation from the four W = 102 mm compact specimens whose data is within the test range described in Reference [12]. The dashed line represents compact specimens with W = 51 mm or 25 mm whose data is within this test range.

The four compact data points are in reasonable agreement with the rectangular compact data; only the data point with the highest J is outside the scatter band of the rectangular compact data, and this point is 9 percent below the scatter band. Further, if both valid and invalid round compact data are used to obtain a three-point and a four-point linear regression line, the resulting intercept values are 99 and 78 N/mm, for the three data points furthest from the blunting line and for all the data, respectively. These intercept values compare favorably with those in Figure 4 for rectangular compact specimens, and although the round compact intercept values are certainly not J_{Ic} values, they are of some use for comparing the round and rectangular compact specimens. This series of tests tends to verify that the round compact specimen can be used for J_{Ic} tests.

SUMMARY AND CONCLUSIONS

The geometry proposed for the round compact specimen is the same as that of the rectangular compact in regard to specimen thickness, crack length, loading hole size and location, and clip-gage location. The portion of the overall diameter to be used as the specimen depth was determined by choosing $D/W = 1.35$. This ratio is larger than that in most of the prior

work, but because it is larger the remaining ligament between the loading hole and the outer surface of the specimen approximates that of the rectangular specimen.

The K solution proposed for the round compact specimen is Newman's wide range expression, Equation (1). Values of the function of a/W in Equation (1) are listed in Table IV for the range of interest in K_{Ic} tests. The expression is considered to be accurate within ± 0.5 percent in the range of interest for K_{Ic} tests as well as over the much wider range of a/W, from 0.2 to 1.0.

Two groups of K_{Ic} tests which compare results from round compact specimens with results from standard C-shaped and rectangular compact specimens showed agreement within ± 2.9 and ± 1.4 percent, respectively.

Based on the tests and analyses described here and considering the general similarity between the round and rectangular compact specimens, we conclude that the round compact specimen and associated K solution described here in Figure 1 and Equation (1) can be included in ASTM Method E-399 as the fourth standard K_{Ic} specimen. The existing compact specimen procedures in E-399, other than specimen geometry and K solution, can be used for K_{Ic} testing with the round compact specimen. In addition, the specimen and K solution is suitable for performing other fracture mechanics tests, such as fatigue crack growth and J_{Ic} tests.

REFERENCES

1. J. C. Newman, Jr., "Stress-Intensity Factors and Crack-Opening Displacements for Round Compact Specimens," NASA TM 80174, Langley Research Center, 1979.
2. J. E. Srawley, International Journal of Fracture, 12, 1976, pp. 475-476.
3. B. Gross, "Mode I Analysis of a Cracked Circular Disk Subjected to a Couple and a Force," Developments in Theoretical and Applied Mechanics, Volume 9, Vanderbilt University, Nashville, TN, 1978, pp. 195-201.
4. D. M. Fisher and R. J. Buzzard, "Comparison Tests and Experimental Compliance Calibration of the Proposed Standard Round Compact Plane Strain Fracture Toughness Specimen," NASA TM 81379, Lewis Research Center, 1979.
5. R. D. Gregory, "The Edge-Cracked Circular Disk Under Symmetric Pin-Loading," Technical Report No. 78-36, The University of British Columbia, Vancouver, October 1978.
6. D. F. Mowbray and W. R. Andrews, "Stress Intensity Factor Calibration for a Compact Specimen with a Round Profile," General Electric Company Technical Information Series, 1975.
7. G. Feddern and E. Macherbauch, Z. Metallkde, 64, 1973, pp. 882-884.
8. J. H. Underwood and D. P. Kendall, "Fracture Toughness Testing Using the C-Shaped Specimen," Developments in Fracture Mechanics Test Methods Standardization, ASTM STP 632, W. F. Brown, Jr. and J. G. Kaufman, Eds., American Society for Testing and Materials, 1977, pp. 25-38.

9. W. R. Andrews, "RCT Specimen Testing, An ASTM Contribution," report to ASTM Task Group E24.01.12, March 1978.

10. J. H. Underwood and D. P. Kendall, Journal of Testing and Evaluation, 6, 1978, pp. 296-300.

11. L. A. James and W. J. Mills, "An Evaluation of the Round Compact Specimen for Fatigue-Crack Growth Rate Testing," Report HEDL-TME 78-56, Westinghouse Hanford Company, June 1978.

12. G. A. Clarke, W. R. Andrews, J. A. Begley, J. K. Donald, G. T. Embley, J. D. Landes, D. E. McCabe, and J. H. Underwood, Journal of Testing and Evaluation, 7, 1979, pp. 49-56.

TABLE I. COLLOCATION K_I AND DISPLACEMENT RESULTS FROM REFERENCE 1 FOR THREE ROUND COMPACT GEOMETRIES;

$\ell/W = 0.275,\ d/W = 0.25$

a/W	Full Round D/W = 1.33 c/W = 0.33 $KBW^{1/2}/P$	Full Round D/W = 1.35 c/W = 0.35 $KBW^{1/2}/P$	Figure 1 Geometry D/W = 1.35 c/W = 0.25 $KBW^{1/2}/P$	 EBv/P
0.2	4.08	4.138	4.115	7.97
0.3	5.63	5.636	5.629	11.48
0.4	7.52	7.505	7.506	17.35
0.5	10.19	10.17	10.17	27.56
0.6	14.55	14.52	14.53	47.01
0.7	22.84	22.81	22.82	90.28
0.8	42.79	42.75	42.76	217.8

TABLE II. K_I FOR ROUND COMPACT SPECIMENS FROM VARIOUS METHODS

	Wide Range Expression D/W = 1.35, Fig. 1 Newman [1]	Collocation Data D/W = 1.35, Fig. 1 Newman [1]		Experimental Compliance D/W = 1.35, Fig. 1 Fisher & Buzzard [4]		Asymptotic Analysis D/W = 1.35 Gregory [5]	
a/W	$f_1 = KBW^{1/2}/P$	f_2	f_2/f_1-1	f_3	f_3/f_1-1	f_4	f_4/f_1-1
0.2	4.125	4.115	-0.002	4.21	0.021	4.781	0.159
0.3	5.629	5.629	0.000	5.61	-0.003	5.924	0.052
0.4	7.510	7.506	-0.001	7.52	0.001	7.597	0.012
0.5	10.17	10.17	0.000	10.20	0.003	10.18	0.001
0.6	14.50	14.53	0.002	14.49	-0.001	14.51	0.001
0.7	22.79	22.82	0.001	22.80	0.000	22.80	0.001
0.8	42.88	42.76	-0.003	42.80	-0.002	42.73	-0.003

	Collocation Data D/W = 1.33 Gross [3]		Finite Element D/W = 1.33 Mowbray & Andrews [6]		Experimental Compliance D/W = 1.33 Feddern & Macherauch [7]		C-Shaped Expression D/W = 1.33 Underwood & Kendall [8]	
a/W	f_5	f_5/f_1-1	f_6	f_6/f_1-1	f_7	f_7/f_1-1	f_8	f_8/f_1-1
0.2	4.745	0.150	-	-	-	-	-	-
0.3	-	-	-	-	5.865	0.042	-	-
0.4	7.613	0.014	-	-	7.300	-0.028	-	-
0.5	-	-	10.18	0.001	10.02	0.015	-	-
0.6	14.53	0.000	14.73	0.016	14.72	0.015	14.32	-0.013
0.7	-	-	22.65	-0.006	22.94	0.007	22.82	0.001
0.8	42.77	0.000	42.52	-0.008	-	-	42.55	-0.008

TABLE III. K_{Ic} FROM ROUND COMPACT SPECIMENS COMPARED WITH RESULTS FROM STANDARD SPECIMENS

	K_{Ic}, $MPa\,m^{1/2}$	
Specimen Number	Round Compact Ref. 9	C-Shaped Ref. 10
1	99.9	102.4
2	91.9	94.6
3	97.9	102.8
4	100.1	99.5
5	92.5	97.6
mean K_{Ic}:	96.5	99.4
standard deviation:	3.99	3.42
W:	38 mm	51 mm
D/W:	1.33	-
c/W:	0.25	-
B/W:	0.50	0.50
$2.5(K_{Ic}/\sigma_{ys})^2/B$:	0.70	0.56

	K_{Ic}, $MPa\,m^{1/2}$	
Specimen Number	Round Compact	Rectangular Compact
1	105.0	105.9
2	102.3	102.6
3	105.2	104.8
4	103.0	110.3
5	106.4	-
mean K_{Ic}:	104.4	105.9
standard deviation:	1.69	3.24
W:	55 mm	46 mm
D/W:	1.35	-
c/W:	0.35	-
B/W:	0.50	0.50
$2.5(K_{Ic}/\sigma_{ys})^2/B$:	0.60	0.73

TABLE IV. $K_I \; BW^{1/2}/P = f(a/W)$ FOR THE ROUND COMPACT SPECIMEN

a/W	f(a/W)	a/W	f(a/W)
0.450	8.71	0.500	10.17
0.455	8.84	0.505	10.34
0.460	8.97	0.510	10.51
0.465	9.11	0.515	10.68
0.470	9.25	0.520	10.86
0.475	9.40	0.525	11.05
0.480	9.55	0.530	11.24
0.485	9.70	0.535	11.43
0.490	9.85	0.540	11.63
0.495	10.01	0.545	11.83
		0.550	12.04

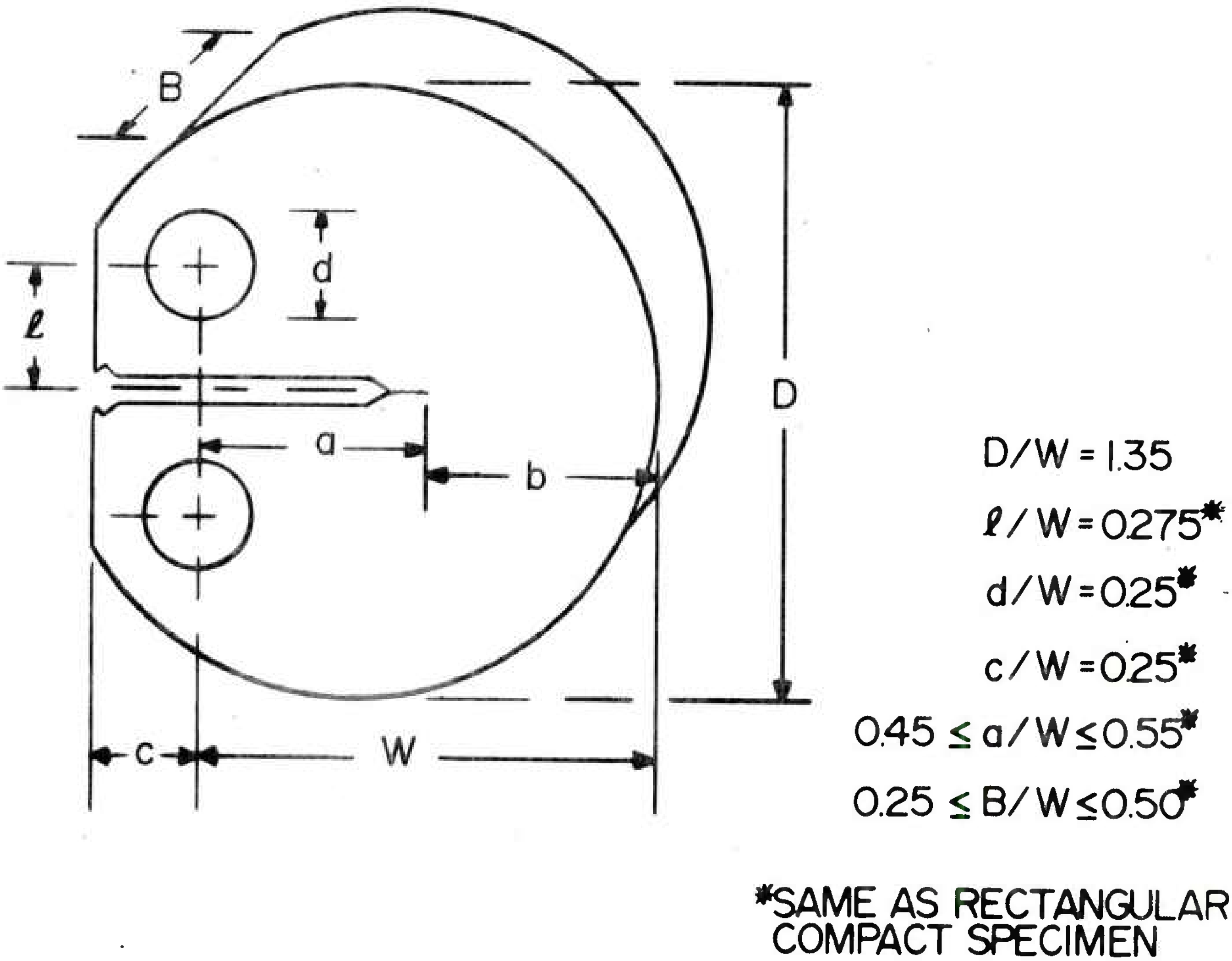

Figure 1. Proposed standard round compact specimen.

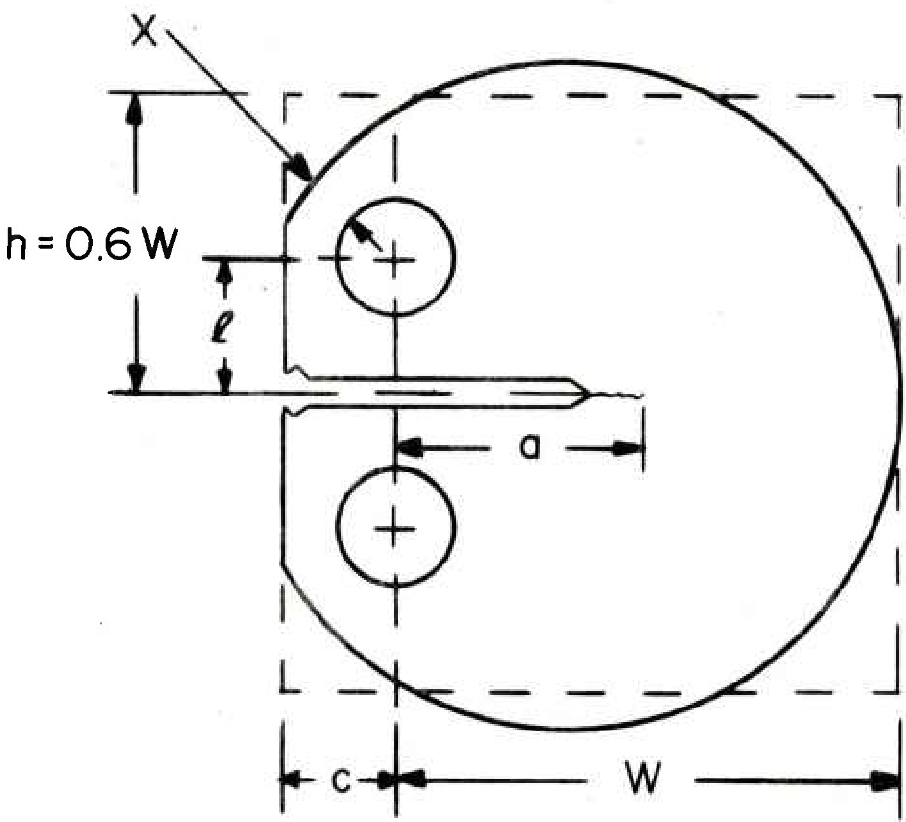

Figure 2. Comparison of round compact specimen with rectangular compact specimen.

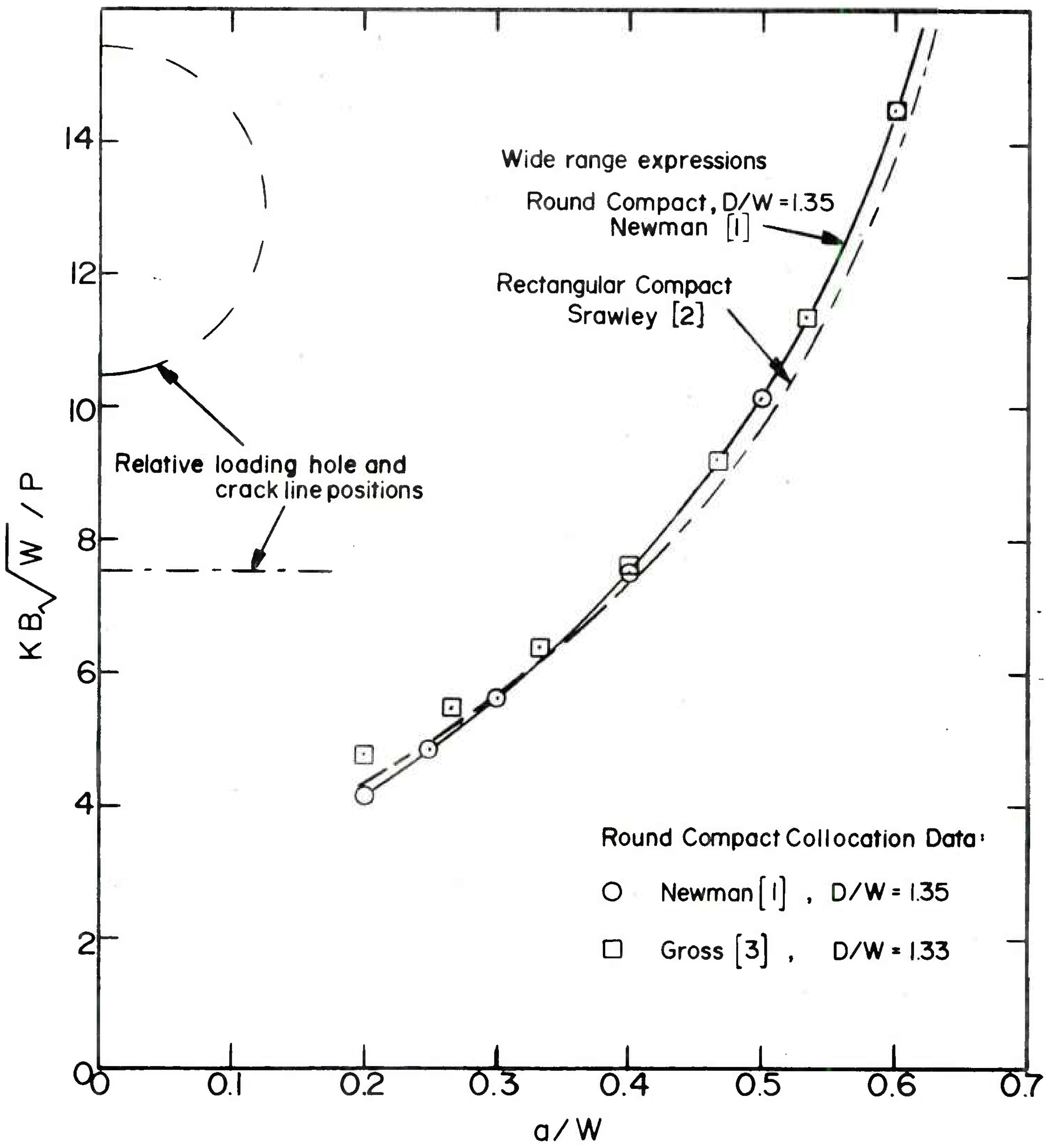

Figure 3. K for round and rectangular compact specimens.

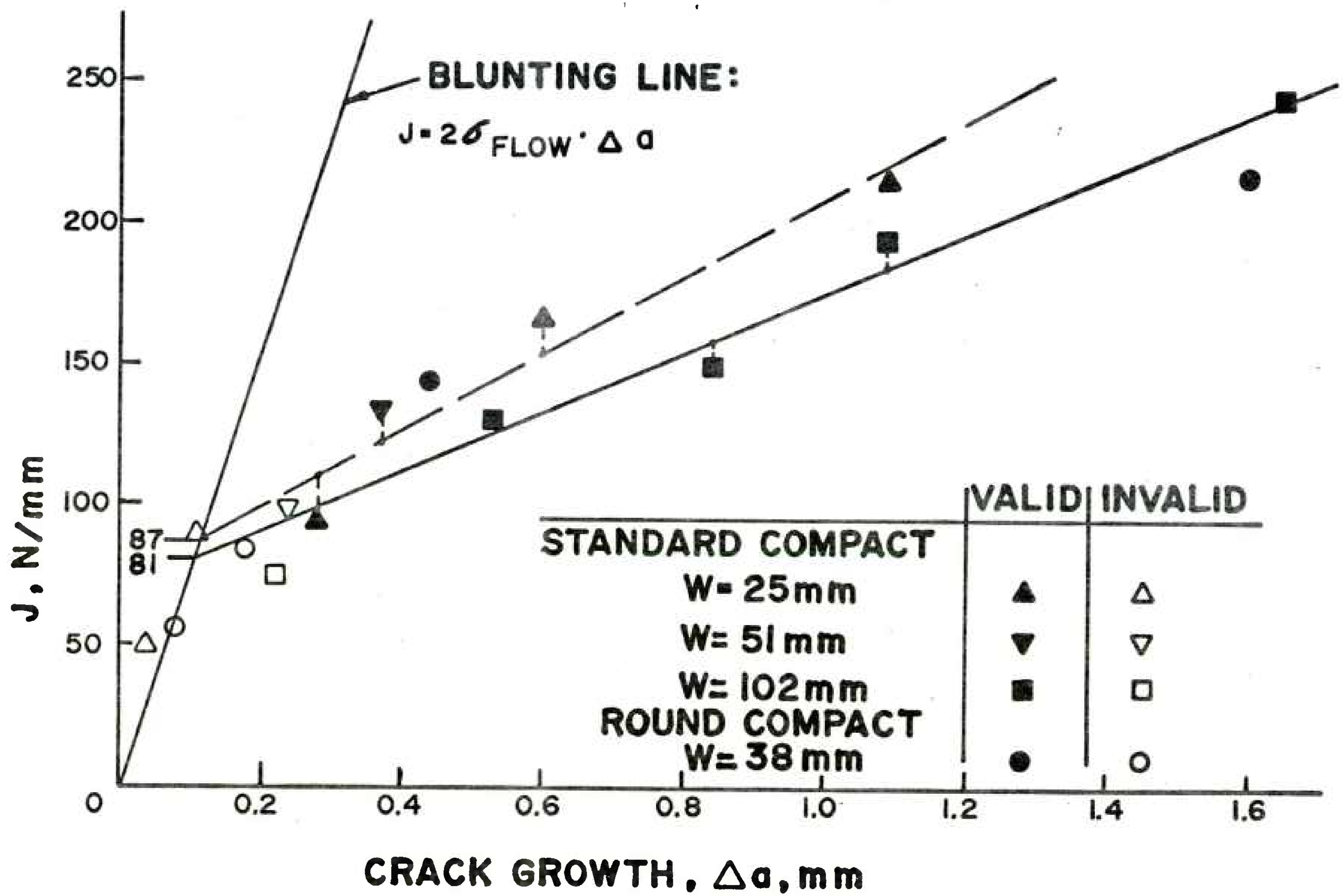

Figure 4. J_{Ic} test results from rectangular and round compact specimens.

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